ZEUS Experiment Reveals What's in a Proton

"To us who breathe only the spirit of our own age, and know only the characteristics of contemporary thought, it is as impossible to predict the general tone of the science of the future as it is to anticipate the particular discoveries which it will make." J.C. Maxwell (1870)

Challenge

Atoms are composed of nuclei and electrons in orbit around them. The nuclei consist of protons and neutrons (members of a family of particles called hadrons). The protons and neutrons, in turn, are made up of quarks. Exactly how the protons (or hadrons in general) are put together and how they stay together are among the outstanding questions in physics.

While we know that protons each contain three quarks, that is not the end of the story: the quarks can emit other particles called gluons, and a gluon can turn into a quark and its anti-particle, the anti-quark, which can emit gluons, and so on. This means that the scene inside a proton is a busy one, with quarks and gluons of different speeds and mass moving and transforming at every turn. Consider that subatomic particles such as quarks, electrons, and positrons can come in left- and right-handed varieties — and add in the possibility of observations of hypothetical particles such as leptoquarks, excited quarks, excited leptons, squarks, and sleptons — and you begin to get some idea of the complexity researchers are discovering in the new physics. One thing they do know: the closer you look, the more complex the structure of the proton appears (Figure 1).

One way to study proton structure is to use electrons as probes. This is what researchers are doing at the Hadron-Electron Ring Accelerator (HERA), the world's only electron-proton collider located in Hamburg, Germany. The ZEUS experiment at HERA — one of the largest high-energy physics experiments operating today — is, in effect, the world's largest electron microscope, allowing scientists to peer deep inside

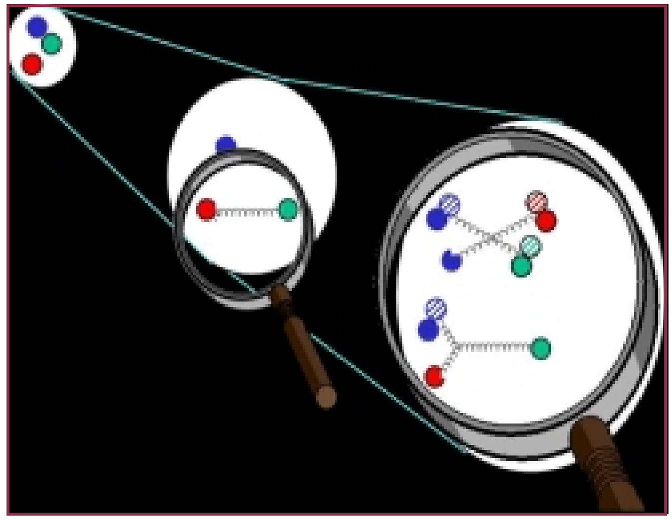

Figure 1. A proton is composed of quarks ("dots" in the picture) and gluons ("springs"). At ZEUS, the electron probes the detailed structure of the proton: the more energetic the electron, the greater its "resolving power."

the proton (Figure 2). Because HERA causes electrons and quarks (which are inside the protons) to collide at higher energies than has ever been done before, the ZEUS experiment has the potential to uncover such new, as-yet only hypothetical, phenomena as super-symmetry or extra dimensions — extending our understanding of the fundamental forces of the universe even as scientists continue the search for new forms of matter and unexpected phenomena.

Argonne's Role

The ZEUS experiment is an international collaboration of 14 countries. A team of physicists from Argonne is one of eight U.S. teams participating in the experiment. The ZEUS experimental apparatus consists of many different components that were built at laboratories and universities around the world and brought together at HERA. The heart of the experiment is a device called the calorimeter, which measures the energies of particles produced in the collisions at HERA. The ZEUS calorimeter, weighing over 700 tons, is better than any other calorimeter at measuring hadrons. A major part of the ZEUS calorimeter was designed and built at Argonne.

Approach

- Electron-proton interactions are a fruitful way of exploring the structure of matter and gaining unsurpassed knowledge about the laws of the microcosm. Protons and electrons are sent flying into each other at nearly the speed of light. If the electron barely changes direction, this means it hit something light; if the electron bounces backward, it hit some-thing heavy. From the resultant scattering angle and energy of the electron, information can be obtained about what the electron encountered in the proton (Figure 3).
- When the electron and the proton collide, the electron scatters, while the proton breaks up into many particles. These collision products are measured in the detector. From these measurements, the characteristics of the collision are reconstructed.
- The calorimeter in the ZEUS experiment determines with high precision the energies, directions, and nature of single particles and particle jets created in subatomic interactions.

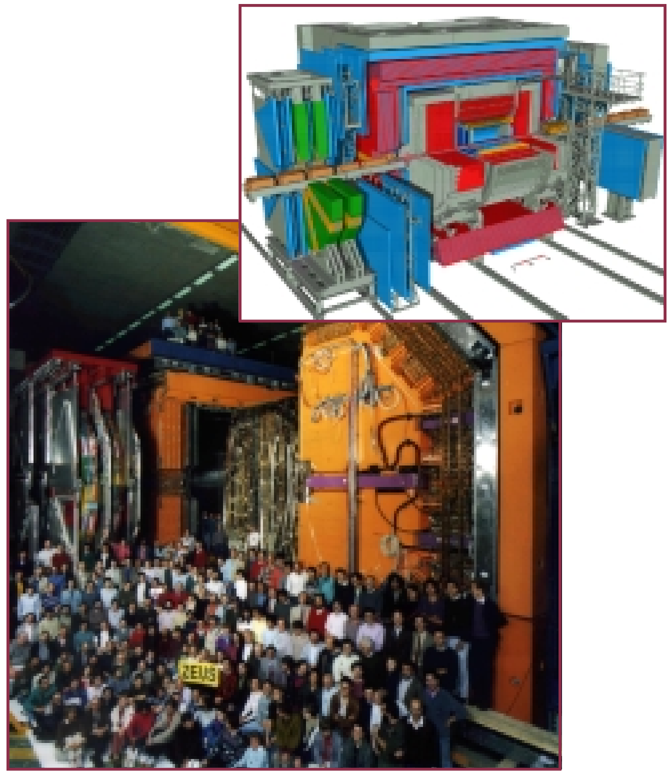

Figure 2. Argonne is part of the ZEUS collaboration, an international team of physicists shown here in front of the ZEUS detector. The detector, which measures 12 m × 10 m × 19 m and weighs 3,600 tons, is used to explore the smallest known particles.

Accomplishments

Since the beginning of its operations in 1992, researchers involved in the ZEUS experiment have published more than 100 scientific papers to extend our understanding of the microcosm. According to the database of high-energy physics publications maintained by the Stanford Linear Accelerator Center, the ZEUS papers are among those most frequently referenced.

Operating the experimental apparatus and analyzing the resulting data in an experiment as large as ZEUS is a team effort. Argonne physicists are very much involved in this effort and hold many leadership positions in the ZEUS collaboration.

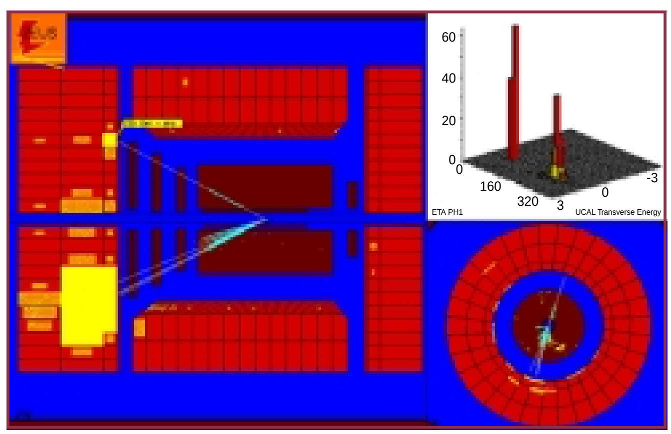

Figure 3. Electrons are accelerated to 30 billion electron volts (GeV) and protons to 820 GeV before they collide.

ZEUS Participants

- Canada
- Federal Republic of Germany
- Greece
- Israel
- Italy
- Japan
- Kazakhstan
- Korea
- Netherlands
- Poland
- Russia
- Spain
- United Kingdom
- United States of America
  - Andrews University
  - Columbia University, Nevis Laboratories
  - Ohio State University, Physics Department
  - Pennsylvania State University, Department of Physics
  - University of California, Santa Cruz
  - University of Wisconsin, Department of Physics
  - Yale University, Department of High-Energy Physics

Contact

Jose Repond
High-Energy Physics
Phone: 630/252-7554
Fax: 630/252-5782
repond@hep.anl.gov

ARGONNE NATIONAL LABORATORY
IS OPERATED BY THE UNIVERSITY OF CHICAGO FOR THE U.S. DEPARTMENT OF ENERGY